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60/187,600 7 March 2000 (07.03.2000) US(71) Applicant: HONEYWELL INTERNATIONAL INC.
[US/US]; 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962 (US).

(72) Inventor: GUALTIERI, Devlin, M.; 12 Moore Street, Ledgeewood, NJ 07852 (US).

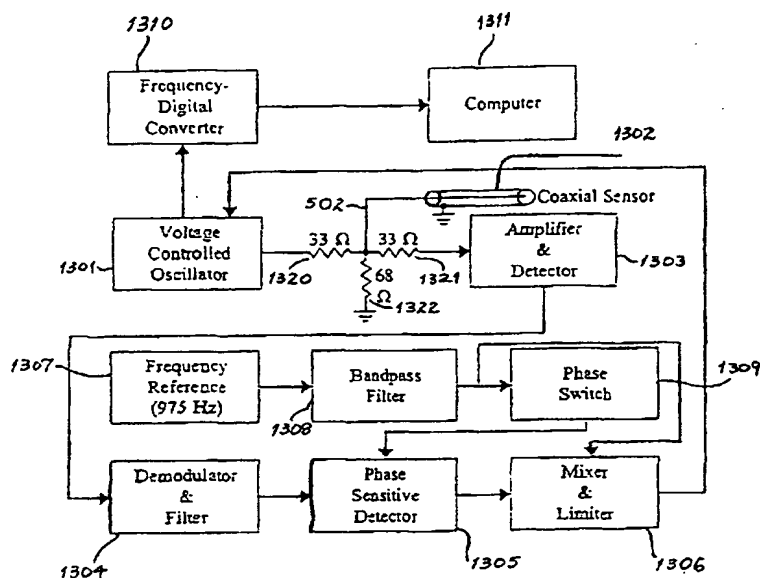
(74) Agents: YEADON, Loria, B. et al.; Honeywell International Inc., 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962 (US).

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(54) Title: APPARATUS AND METHOD FOR MEASURING THE LEVEL OF A FLUID



(57) Abstract: An apparatus for detecting a fluid level is disclosed, which includes a coaxial sensor (1302) having a pair of conducting tubes positioned with respect to each other in spaced coaxial arrangement, a coaxial transmission line (502) connected to the sensor, a means (1301) for injecting a standing wave into the coaxial sensor, a summer (1320, 1321, 1322) for summing the injected wave and a reflected wave connected to the sensor, a means for adjusting (1305) the frequency of the injected wave in response to the voltage and phase of the summed signal, and a processor (1311) for processing and displaying the frequency as a representation of the level of the fluid. A method for detecting the fluid level is also disclosed.

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APPARATUS AND METHOD FOR MEASURING THE LEVEL OF A FLUID

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BACKGROUND OF THE INVENTION**1. Field of the Invention**

The present invention relates generally to an apparatus and method for measuring the level of a fluid. More particularly, the present invention utilizes standing wave
10 reflectivity of a coaxial transmission line to determine the level of a fluid in which the coaxial transmission line is immersed.

2. Description of the Related Art

There are many ways to measure the level of a fluid, and the techniques are numerous since fluids have many physical properties that can be exploited. These
15 properties include the temperature, weight, capacitance, density, resistance, etc., of the fluid.

Examples of various techniques and devices include thermal fluid level sensors. Fluids have a heat capacity and thermal conductivity that is different from air. Small heating elements will have different temperatures whether they are in, or out, of the fluid.
20 Another method uses capacitance to measure the level of the fluid. Since the dielectric constant of a fluid is different than that of air, capacitor plates having an intervening fluid will have a larger capacitance. Resistive and eddy current techniques have also been utilized. Since some fluids are electrically conducting, electrodes will carry current when immersed in a fluid. Eddy current losses for a coil will be higher when the coil is
25 immersed in a conductive liquid.

Magnetostrictive techniques are also popular. This technique uses a combined magnetic and ultrasonic effect. It is possible to magnetically generate twist pulses in a wire (the Wiedemann Effect), which propagate at the speed of sound in the material and are reflected at the point at which the wire enters the liquid. The time of flight is used to measure the fluid level. Fiber optic technology is also utilized. The index of refraction difference between a glass fiber and the fluid can be used to optically detect the fluid level. Ultrasonic ranging is yet another method readily available. Since the time of flight of an ultrasonic pulse differs while propagating either in the fluid or in air, the difference can be used to detect fluid level. Ultrasonic damping has also been exploited.

Acoustically resonant elements (e.g., ultrasonic transducers) will be damped by a fluid, that is, it will take more energy to excite them at a given amplitude. The time of flight of a radar pulse is also used to detect the surface of the fluid. This is usually not useful for small containers, although micropower impulse radar (MIR) will work at short range. Finally, a pressure sensor at the bottom of a container will gauge the weight of the fluid above it.

Though each of these techniques and sensors has a specific use, no one device or method provides an accurate fluid level measurement suitable for various applications.

SUMMARY OF THE INVENTION

It is therefore an aspect of the present invention to provide an apparatus and method for measuring the level of a fluid. The preferred embodiment of the present invention incorporates a novel approach using frequency domain analysis (FDA) of standing wave resonance (SWR) in a coaxial transmission line. It is based on the principle that the speed of light is slower in a fluid than in air. The sensor is applicable to

level sensing for a wide variety of fluids, including oil and water. The sensor also functions in very harsh fluids (e.g., acids) with a proper choice of materials.

BRIEF DESCRIPTION OF THE DRAWINGS

5 The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a diagram of reflected waves in a transmission line;

FIG. 2 is a block diagram of an apparatus to measure standing wave voltage in a
10 transmission line in the frequency domain;

FIG. 3 is a graph of the standing wave response of a 90-inch length of 50-ohm coaxial cable in the frequency domain;

FIG. 4 is a perspective view of a fluid level sensor constructed according to an embodiment of the present invention;

15 FIG. 5 is a block diagram of an apparatus used to measure standing wave voltage according to an embodiment of the present invention;

FIG. 6 is a graph of the frequency domain standing wave spectrum of the fluid level sensor of FIG. 5;

FIG. 7 is a graph of the frequency shift of a first node of the sensor versus a level
20 of pump oil in the sensor;

FIG. 8 is a graph of the frequency domain standing wave spectrum of a 36-inch fluid level sensor coupled by a 90-inch length of 50-ohm coaxial cable;

FIG. 9 is a perspective view detailing the fluid level sensor according to one embodiment of the present invention;

FIG. 10 is a graph of the frequency response of a delay line sensor;

FIG. 11 is a graph of the sensitivity of a sensor for measuring the fluid level of pump oil;

FIG. 12 is a graph depicting the measurement principle for the electronic interface of the sensor according to an embodiment of the present invention;

FIG. 13 is a block diagram of the electronic interface according to an embodiment of the present invention;

FIGS. 14A and 14B illustrate input signals requiring calibration;

FIG. 15 is a graph of a change in the detector voltage about the node frequency for a 36-inch fluid level sensor; and

FIG. 16 is a perspective view of the open end of the fluid level sensor according to a further embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A preferred embodiment of the present invention will be described herein below with reference to the accompanying drawings.

In attempting to solve the longstanding sensor problems time domain reflectometry (TDR) was experimented with as a sending method in a coaxial type sensor. The reflected signals from transmission lines of various lengths driven by a 10 MHz square wave oscillator with a small rise-time were tested. The transmission lines were terminated with a 150-pF capacitor to simulate the transition to a fluid surface. Although the transit times of the reflected signals correspond to the lengths of the transmission lines, the transit times are short (nanosecond range) and hard to measure.

As an alternative to TDR, an investigation into standing wave reflectance in the frequency domain in transmission lines was explored. FIG. 1 shows reflected waves in a transmission line. The upper graph depicts an injected and reflected wave pattern satisfying the following equation:

5
$$L=(n+1/2)\lambda \quad \text{Eq. 1}$$

where L is the length of the transmission line, λ is the wavelength of the injected wave, and n is a whole integer from 0 to ∞ . When the length of the transmission line is an $n+1/2$ multiple of the wavelength, there is destructive interference and the signal strength is a minimum (a node). Four nodes 101, 102, 103 and 104 are shown in Fig 1. As the
10 length varies from this condition, as shown in the lower graph of Fig. 1, the interference condition is not met, and there is a net voltage at the driven end, i.e. the difference between points a and b. In the fluid level sensor, the physical length of the transmission line is held constant, but the level of the fluid changes the effective electrical length.

FIG. 2 shows an apparatus to measure the standing wave voltage in a coaxial
15 transmission line in the frequency domain. A frequency synthesizer 210 inputs or injects a sine wave signal into the transmission line at input point 260. The signal is reflected at the end of the transmission line 200 back to the input point 260. The resistor "T" network, comprised of resistors 230, 240 and 250, sums the injected and reflected waves at the input point 260 of the transmission line 200. A lock-in amplifier 220 measures the
20 voltage difference between the injected wave and the reflected wave at the input 260 of the transmission line 200. Although the far end of the transmission line is shown here as open, a termination in any impedance other than the characteristic impedance of the transmission line will also reflect the signal. If Eq. 1 is satisfied the voltage difference will be nearly zero; if not, a substantial voltage will be detected that is relative to the
25 length of the transmission line 200.

FIG. 3 shows the standing wave response of a 90-inch length of 50-ohm coaxial cable in the frequency domain using the apparatus of FIG. 2. In this case, a first node 301 appears at slightly less than 30 MHz, with other nodes 302, 303 and 304 at regular intervals. Also apparent are minor stray voltages 305 and 306 caused by impedance discontinuities in the measuring system (e.g., the impedance of the "T" network not exactly matching the transmission line impedance).

Therefore, as shown in the prior art, when Eq. 1 is satisfied the sum of the voltage of the injected wave and the voltage of the reflected wave measured at the input of the transmission line will nearly equal zero. When the length of the transmission line varies, and in the event Eq. 1 is not satisfied, a voltage at the input of the transmission line will be produced.

FIG. 4 depicts a fluid level sensor constructed according to an embodiment of the present invention. The coaxial sensor 400 is constructed from commonly available copper pipes arranged as an air dielectric coaxial transmission line having an impedance of 29 ohms. The coaxial sensor 400 is made from a 12-inch length of 16 mm outside diameter (O.D.) inner tubing 401 inside a 12-inch length coaxial outer tube 402 of 26 mm inside diameter (I.D.). In the preferred embodiment of the present invention, the length of the inner tube 401 is equal to the length of the outer tube 402. Nylon bolts 403 pass through outer tube 402 and serve to hold the inner tube 401 in place. Nylon was chosen for its insulating properties. Though not shown in Fig. 4, outer tube 402 is electrically connected to ground and inner tube 401 is electrically connected to an inner conductor of a coaxial cable. When fluid enters into the coaxial sensor between the outer tube 402 and the inner tube 401, the fluid decreases the effective length of the overall sensing element (i.e. the coaxial sensor 400 and the connected coaxial cable) of the fluid level sensor and as a result the standing wave voltage will change. The length of the

coaxial cable is important, since the cable is part of the resonant transmission line and is factored in during the calculation of Eq. 1.

FIG. 5 depicts the apparatus according to the preferred embodiment of the present invention used to measure the standing wave voltage. Shown in Fig. 5 are a 12-inch
5 copper coaxial sensor 501 whose outer tube is shown connected to ground, a 94-inch coaxial cable 502 whose inner conductor 508 is shown connected to the inner tube of the coaxial sensor 501, a resistor "T" network (comprised of resistors 505, 506, and 507), a frequency synthesizer 503, and a lock-in amplifier 504. The frequency synthesizer 503 is used to inject a sine wave into the coaxial cable 502 and the coaxial sensor 501 (the
10 combination of which will hereinafter be referred to as the "sensing element") at the input 509 of the sensing element. The injected wave reflects back from the end of the sensing element, where the resistor "T" network adds the voltage of the injected wave to the voltage of the reflected wave, the sum of which is input into signal port 510 on the lock-in amplifier 504. The initial injected wave is also sent to a reference port 511 on the
15 lock-in amplifier to serve as a calibration reference.

FIG. 6 shows the frequency domain standing wave spectrum of the coaxial fluid level sensor of FIG. 5 when tested with standard pump oil. There is a clear first node 601 at about 17 MHz with subsequent nodes 602, 603, and 604 at regular intervals graphically illustrating the satisfying of Eq. 1. The calculated impedance of this coaxial
20 sensor is 29-ohms. The impedance of the coaxial cable is 50-ohms. Even with such a mismatch there are deep standing wave nulls arising from reflections in the total 106-inch length (i.e. 94-inch coaxial cable 502 plus the 12-inch coaxial sensor 501). The RF amplitude at the input 509 of the sensing element in the embodiment shown in Fig. 5 averages about 40-millivolt rms. Smaller input signals in the microvolt levels can be

used as the injected wave, and amplifiers and filters incorporated into the lock-in amplifier are utilized to detect and measure the microvolt levels.

FIG. 7 shows the frequency shift of the first node 601 of Fig. 6 of the fluid level sensor versus the level of pump oil in the sensor. A nearly linear decrease in the node
5 frequency with fluid depth is shown, and is calculated at about 67 kHz per cm of fluid.

In accordance with the present invention, both standard pump oil and Skydrol® hydraulic fluid were utilized. Skydrol® is an aviation hydraulic fluid with excellent hydraulic properties, but it is a caustic liquid, and this limits the type of materials from which a sensor can be constructed. A substantial compatibility guide for Skydrol® can be
10 found at <<http://www.skydrol.com/compat.htm>>. Since the materials of a copper coaxial sensor, as used to measure the level of pump oil, are not compatible with Skydrol® hydraulic fluid, in a second embodiment of the present invention the inner and outer tubes of a 36-inch length sensor are constructed from aluminum and Teflon, which are both Skydrol® compatible.

15 The impedance of an air dielectric coaxial transmission line is given by the following equation:

$$Z = 138 \log_{10} (b/a) \quad \text{Eq. 2}$$

where “Z” is the impedance in ohms, “b” is the inside diameter (I.D.) of the outer conductor, and “a” is the outside diameter (O.D.) of the inner conductor. By matching
20 the impedances of the coaxial sensor and the coaxial cable the stray voltages (e.g. 605 and 606 as shown in Fig. 6) are reduced to a minimum, thus ensuring proper nodal detection.

Table 1 is a sensor impedance chart with the inside diameter (I.D.) of the outer conductor (in inches) across the top, and the outside diameter (O.D.) of the inner
25 conductor (in inches) on the left side. As shown in Table 1, choosing a 0.759-inch I.D.

outer conductor and 0.3125-inch O.D. inner conductor results in a 53.2-ohm impedance, close to the desired 50-ohm impedance of the coaxial cable.

TABLE 1

| I.D. | | 1.25 | 0.902 | 0.759 | 0.652 | 0.527 |
|--------|--|-------|-------|-------|-------|-------|
| O.D. | | | | | | |
| 0.75 | | 30.6 | 11.1 | 0.7 | | |
| 0.625 | | 41.5 | 22.0 | 11.6 | 2.5 | |
| 0.375 | | 72.2 | 52.6 | 42.3 | 33.1 | 20.4 |
| 0.3125 | | 83.1 | 63.5 | 53.2 | 44.1 | 31.3 |
| 0.25 | | 96.5 | 76.9 | 66.6 | 57.5 | 44.7 |
| 0.1875 | | 113.7 | 94.1 | 83.8 | 74.7 | 61.9 |

5

According to the second embodiment of the present invention, the 36-inch coaxial sensor of 53.2-ohms impedance is electrically connected to a 90-inch length of coaxial cable, producing a sensing element of 126 inches. FIG. 8 shows the frequency domain standing wave spectrum of this embodiment. There is a clear first node 801 at about 15 MHz that is easily detected by the amplifier.

As stated above with reference to Fig. 7, the response of the 12-inch copper tubing sensor to pump oil was about 67 kHz/cm. Utilizing the 36-inch sensor with Skydrol[®], the response is nearly an order of magnitude higher. This is the result of the much lower speed of light in this high dielectric liquid. By adjusting to allow less of the fluid into the coaxial sensor, i.e. by using a glass tube over the inner conductor to prevent the Skydrol[®] from filling the entire inner space, the sensitivity of the sensor is reduced. According to a third embodiment of the present invention, FIG. 9 shows the Skydrol[®] fluid level sensor 900 having an outer aluminum cylinder 901, an inner aluminum conductor 902 partitioned by a glass tube 903, and nylon spacers 904. To linearize the sensor, the inner glass tube has a variable cross-section that adjusts fluid volume along the length of the sensor.

It is also possible to modify the present invention such that the sensitivity may be increased so that smaller sensors can be used to monitor smaller volumes. In another embodiment of the present invention, the inner conductor is formed as an inductor by winding it as a helical coil to increase the electrical length of a transmission line.

- 5 Forming this coil on a magnetic core such as ferrite further increases the coil inductance and the delay. The delay is actually an increase in the time required for the injected wave to reflect and return due to the increased transmission length of the sensing element.

FIG. 10 and FIG. 11, respectively, show the frequency response and the sensitivity of this embodiment, in which the coaxial sensor is formed with an inductor
10 surrounded by the outer conductor to create a delay line sensor. FIG. 11 shows the sensitivity of the delay line sensor utilizing pump oil for this embodiment. A first node 1001 is clearly visible and easily detectable by an amplifier and detector. The electrical length (half the standing wave wavelength) is 2.2 meters, about five times the physical length. This is a useful sensor for small vessels in the liter volume range. The vertical
15 axis in FIG. 11 is a measure of the electrical length of the sensor.

Fig. 12 illustrates a measurement principle according to the preferred embodiment of the present invention. The first standing wave node 1201 is used for measurement calculations. As a general overview, a sine wave is injected into the sensing element. The lock-in amplifier detects the first node 1201, calculates the
20 derivative of the RF amplitude, and adjusts the frequency of the sine wave of the frequency synthesizer until the calculated derivative equals zero, thus calibrating the system. As the fluid in the coaxial sensor changes, the amplitude of the standing wave is measured at the resistor "T" network and translated into a fluid level via a look-up table or algorithm stored in a system memory. Further explanation will be discussed with
25 reference to FIG. 13.

FIG. 13 is a block diagram of the preferred embodiment of the present invention. The operation of the invention will be described in conjunction with FIG. 13. The frequency synthesizer 503 of FIG. 5 has been replaced by a voltage-controlled oscillator (VCO) 1301. The VCO produces a sine wave signal that is injected into the coaxial sensor 1302 through the coaxial cable. This signal, upon reaching the end of the coaxial sensor 1302, whether that end is the physical end of the cable itself or an end created by the level of the fluid, reflects back to produce a reflected signal. The injected signal and the reflected signal are summed by the resistor "T" network (comprised of resistors 1320, 1321, and 1322) and forwarded to the amplifier-detector 1303. The amplifier-detector 1303 receives the signal, amplifies it and demodulates it from the RF component, to produce a signal to be analyzed by the remaining circuitry. A frequency reference 1307 produces a square wave, which is processed by a bandpass filter 1308 to produce a clean sine wave. This modulated sine wave is also processed by a phase switch 1309 to produce a control signal for a phase sensitive detector 1305. The phase-sensitive detector 1305 and control loop produces a small frequency modulating voltage to control the VCO 1301. The detected signal output from the amplifier - detector 1303 is filtered at demodulator and filter 1304 and fed into the phase sensitive detector 1305, which is controlled by the phase switch control signal produced by phase switch 1309. After mixing and filtering at mixer and limiter 1306, the amplitude of the signal is synchronously detected to produce a signal proportional to the frequency derivative of the signal. If the oscillator frequency is on the low side of a node in the amplitude-frequency spectrum, the phase sensitive detector 1305 produces a signal that increases the frequency of VCO 1301 to bring it into the node. Likewise, if the oscillator frequency is on the high side of a node in the amplitude-frequency spectrum, the phase detector 1305 produces a signal that decreases the frequency of VCO 1301 to bring it into the

node. This control loop acts to force the VCO 1301 to track the node. FIGS. 14A and 14B illustrate input signals requiring calibration.

FIG. 14A shows the phase relationship of the signal from detector 1305 and control signal of phase switch 1309 at a frequency that is less than the node frequency, and FIG. 14B shows the same signals when the frequency is greater than the node frequency. The node frequency is a function of the overall length of the sensor and cable, and is the frequency adjusted for the minimum amplitude during a no-load state. In the case depicted in FIG. 14A, the phase relationship will cause a voltage to be added to the control loop of the VCO 1301 to increase the frequency to bring it back into the node. Likewise, in the case depicted in FIG. 14B, the phase relationship will cause a voltage to be subtracted from the control loop of the VCO 1301 to decrease the frequency to bring it back into the node. FIG. 15 shows the actual change in the detector voltage about the node 1501 for the 36-inch fluid level sensor.

Referring back to FIG. 13, after calibration is complete, the frequency of the VCO 1301 (which is the frequency of the node) is digitized at converter 1310 and sent to a computer 1311. The frequency-digital converter 1310 is preferably a simple analog-to-digital (A/D) converter. This frequency is a function of the fluid level in the coaxial sensor, and a look-up table or algorithm is utilized to determine the level of the fluid.

The circuit implementation described above uses signal generation, and adjusting and detection circuitry to accomplish the desired result, but is not meant to be exclusive as the only method of generating, adjusting and detecting the signals. As shown in FIG. 13, the computer 1311 can be used to interface to the present invention. A program accepts the data through a parallel port, processes the data and produces a fluid level value. The program can also incorporate a data-logging feature.

There are three factors that require system compensation and will now be described as further embodiments of the present invention. First, temperature changes in the fluid during measurement will affect the accuracy of the system. To compensate for this fluid property, a thermometer can be used to measure temperature variations that can be processed by the computer to compensate therefore. As an alternative, a second sensing element can be added to the overall system and filled with the same fluid being measured, where the second sensing element acts as a reference to detect and store changes in fluid properties during normal operations. This reference data is processed by the computer and incorporated into the final level calculations. Second, fluid level measurement errors can be generated by excess fluid adhering to the sides of the inner and outer tubes. To reduce these errors, a Teflon[®] coating to the tubes prevents adherence and improves overall accuracy. Finally, level measurement errors generated by a sloshing effect caused by movement of the fluid can be detected. FIG. 16 is a diagram of an open end of a fluid level sensor according to a further embodiment of the present invention showing the outer conductor 1601 and the inner conductor 1602. To correct for this sloshing effect an end plug 1603 with a few small entry holes 1604 will eliminate error from sloshing, since it limits the rates of inflow and outflow of the sensor. A small hole (not shown) is also needed at the top of the sensor for outflow of air.

While the invention has been shown and described with reference to a certain preferred embodiment thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

WHAT IS CLAIMED IS:

1 1. An apparatus for detecting the level of a fluid, comprising:
2 a radio frequency transmission line;
3 a conductor proximate to the transmission line providing a return current path,
4 wherein said conductor is spaced from the transmission line by insulating spacers to
5 provide a characteristic impedance;
6 generating means for generating a standing wave, said generating means
7 connected to the transmission line;
8 summing means for summing the standing wave and a reflected wave, said
9 summing means connected between the generating means and the transmission line;
10 a detector for detecting the voltage and phase of the summed standing wave and
11 reflected wave;
12 means for adjusting the frequency of the generating means in response to the
13 voltage and phase of the summed signal; and
14 means for comparing the adjusted frequency with reference data for determining
15 the level of the fluid.

1 2. The apparatus of claim 1, wherein the summing means is a "T" network,
2 including:
3 a first resistor connected to the output of a voltage controlled oscillator;
4 a second resistor connected to a amplifier/detector; and
5 a third resistor connected to a system ground;
6 wherein each resistor is connected to the transmission line.

1 3. An apparatus for detecting the level of a fluid, comprising:
2 a radio frequency transmission line;
3 a conductor proximate to the transmission line providing a return current path,
4 wherein said conductor is spaced from the transmission line by insulating spacers to
5 provide a characteristic impedance;
6 generating means for generating a standing wave at a fixed frequency, said
7 generating means connected to the transmission line;
8 summing means for summing the standing wave and a reflected wave, said
9 summing means connected between the generating means and the transmission line;
10 a detector for detecting the voltage and phase of the summed standing wave and
11 reflected wave; and
12 means for comparing the detected voltage and phase with reference data for
13 determining the level of the fluid.

1 4. An apparatus for detecting a fluid level, comprising:
2 a coaxial sensor immersed in a fluid;
3 means for injecting a radio frequency wave into said coaxial sensor;
4 means for summing said injected wave and a reflected wave, said means
5 electrically connected to said coaxial sensor;
6 means for adjusting the frequency of the injected wave in response to a voltage
7 and phase of the summed signal; and
8 means for processing and displaying the frequency as a representation of fluid
9 level.

1 5. The apparatus of claim 4, wherein the coaxial sensor comprises a first
2 electrically conductive tube, and a second electrically conductive tube positioned within
3 the first tube and secured by at least one insulator, wherein an inside diameter of the first
4 tube is greater than an outside diameter of the second tube.

1 6. An apparatus for detecting a fluid level, comprising:
2 a coaxial radio frequency transmission line sensor immersed in a fluid;
3 means for injecting a radio wave of a fixed frequency into said coaxial
4 transmission line sensor;
5 means for summing said injected wave and a reflected wave, said means
6 electrically connected to said coaxial radio frequency transmission line sensor;
7 means for detecting the voltage and phase of the result of the summing of the
8 injected wave and reflected wave; and
9 means for comparing the detected voltage and phase with reference data for
10 determining the level of the fluid.

1 7. An apparatus for detecting a fluid level, comprising:
2 a radio frequency transmission line;
3 a conductor proximate to the transmission line providing a return current path,
4 wherein said conductor is spaced from the transmission line by insulating spacers to
5 provide a characteristic impedance;
6 generating means for generating a standing wave, said generating means
7 connected to the radio frequency transmission line;
8 summing means for summing the standing wave and a reflected wave, said
9 summing means connected between the generating means and the transmission line;

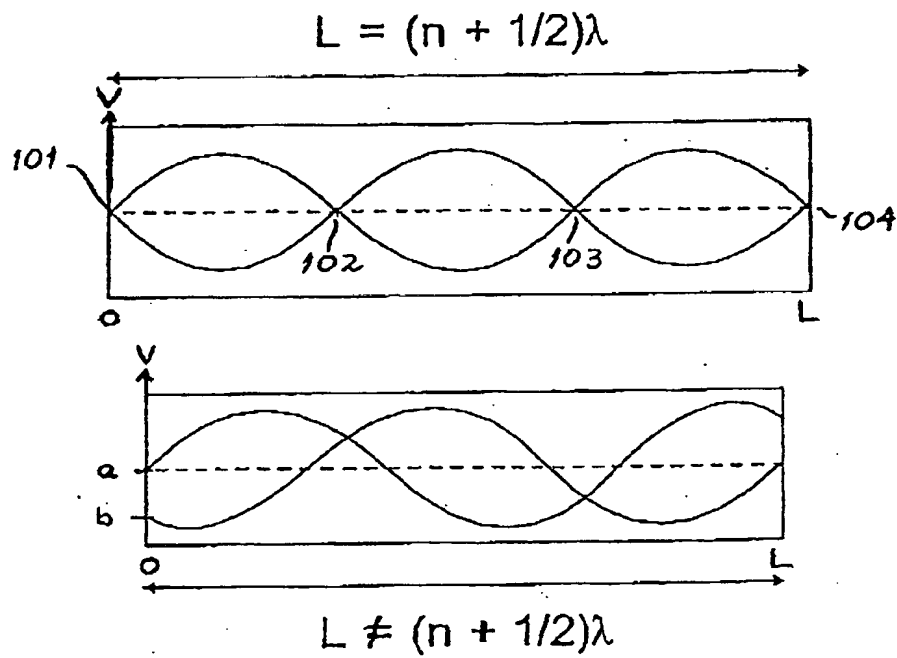
10 an amplifier connected to the transmission line, for amplifying the sum of the
11 standing wave and the reflected wave;
12 an A/D converter connected to an output of the amplifier; and
13 a computer connected to the A/D converter for processing digital data received
14 from the A/D converter.

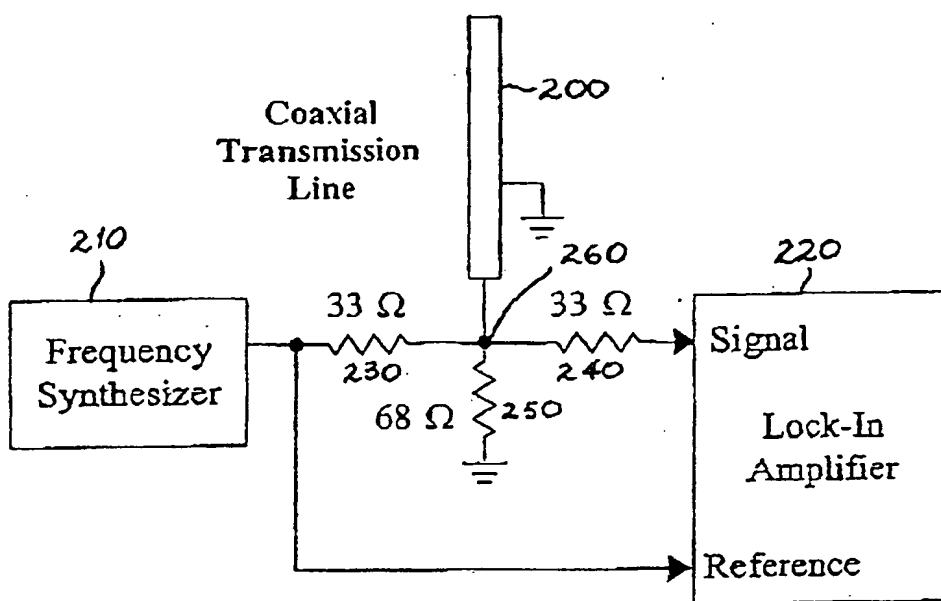
1 8. A method for detecting a level of a fluid, comprising the steps of:
2 inserting a radio frequency transmission line into a fluid;
3 introducing a radio frequency voltage into the transmission line;
4 detecting a voltage that is the sum of the introduced radio frequency voltage and
5 a standing wave voltage reflected by the end of the transmission line; and
6 determining the level of the fluid by comparing the summed voltage with stored
7 fluid level reference data.

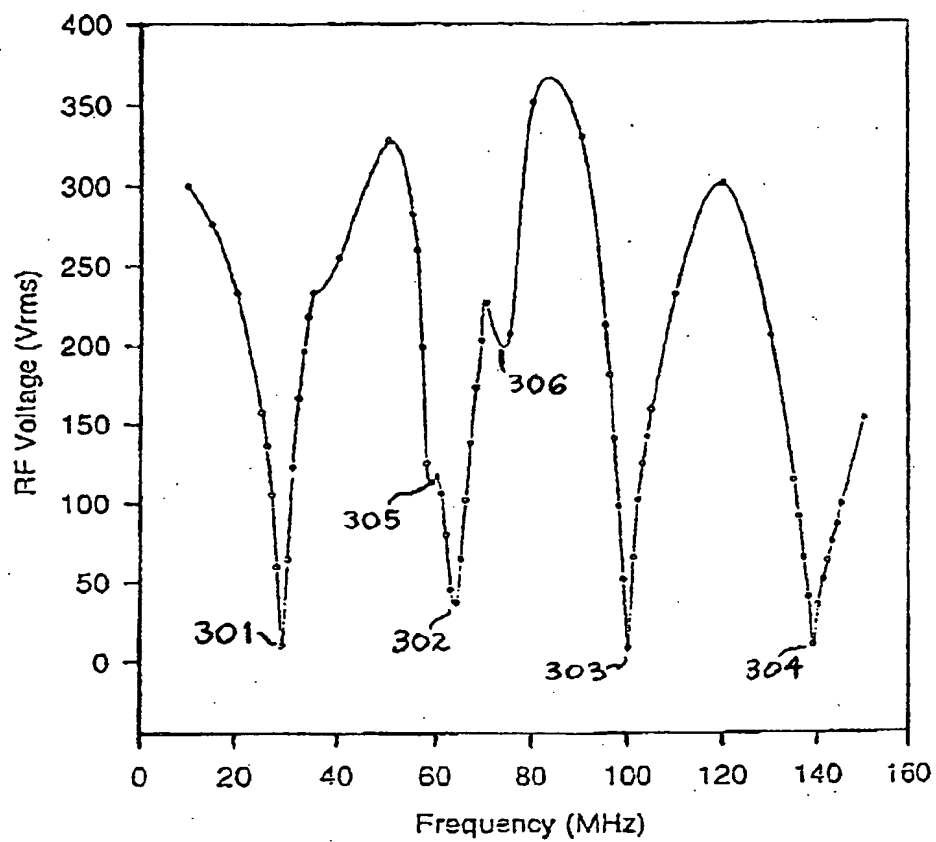
1 9. An apparatus for detecting the level of a fluid, comprising:
2 a sensor having a first tube constructed of electrically conductive material having
3 an inside diameter and a second tube constructed of electrically conductive material
4 having an outside diameter, said outside diameter of the second tube being less than said
5 inside diameter of the first tube, wherein said second tube is affixed inside of said first
6 tube by insulating spacers;
7 a coaxial cable connected at a first end to said second tube;
8 generating means for generating a standing wave, said generating means
9 connected to a second end of said coaxial cable for introducing the standing wave into
10 the coaxial cable;

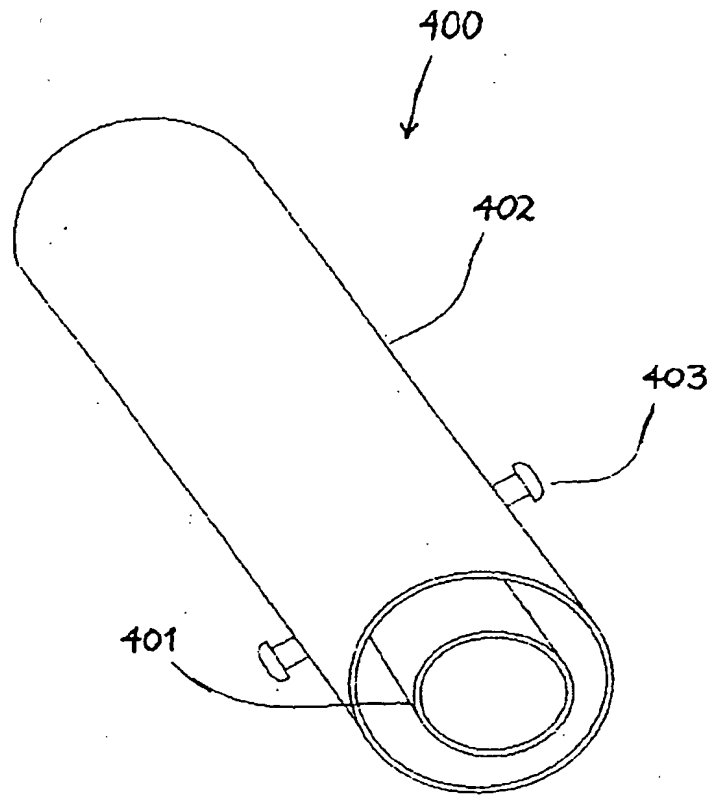
11 summing means for summing the standing wave and a reflected wave, said
12 summing means connected to the second end of the coaxial cable;
13 a voltage detector for detecting a voltage of the summed standing wave and
14 reflected wave; and
15 means for comparing the detected voltage level with reference data for
16 determining the level of the fluid.

1 10. The apparatus of claim 9, wherein the summing means is a "T" network,
2 including:
3 a first resistor connected to the output of a voltage controlled oscillator;
4 a second resistor connected to a amplifier/detector; and
5 a third resistor connected to a system ground;
6 wherein each resistor is connected to a second end of said coaxial cable.
7

**FIG. 1****PRIOR ART**

**FIG. 2****PRIOR ART**

**FIG. 3****PRIOR ART**

**FIG. 4**

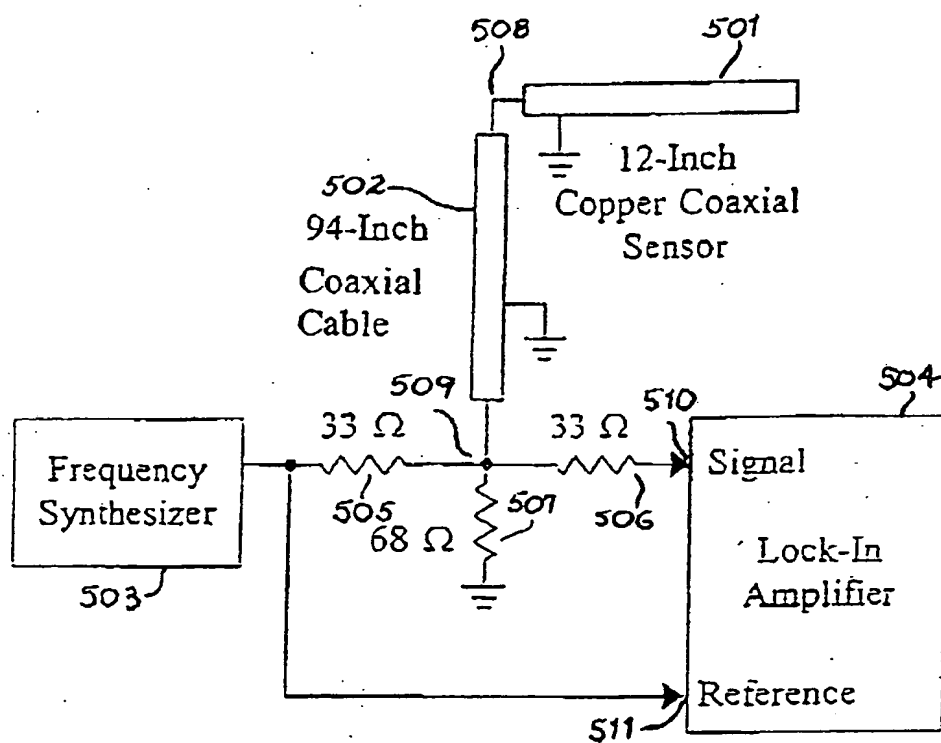
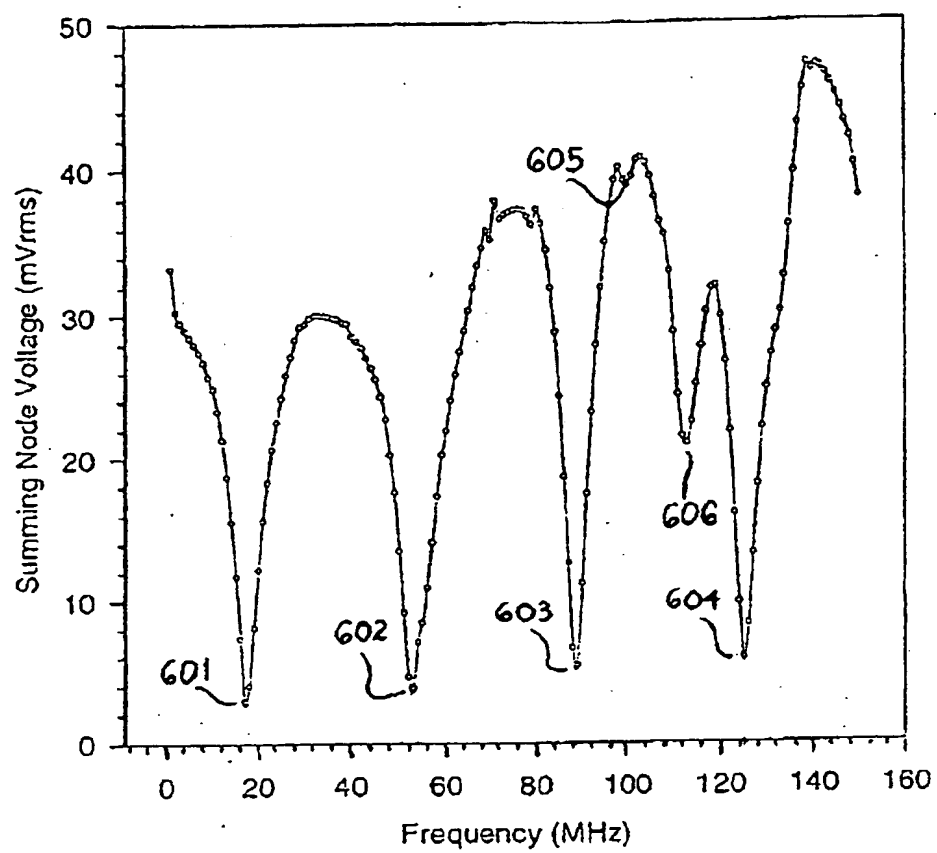
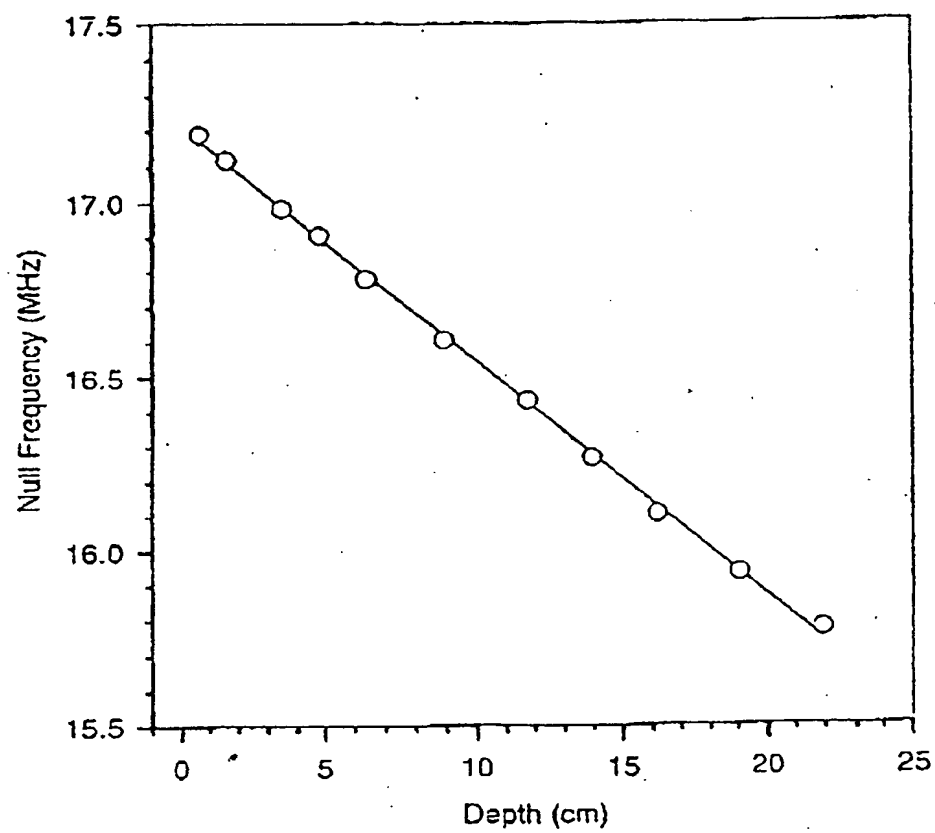
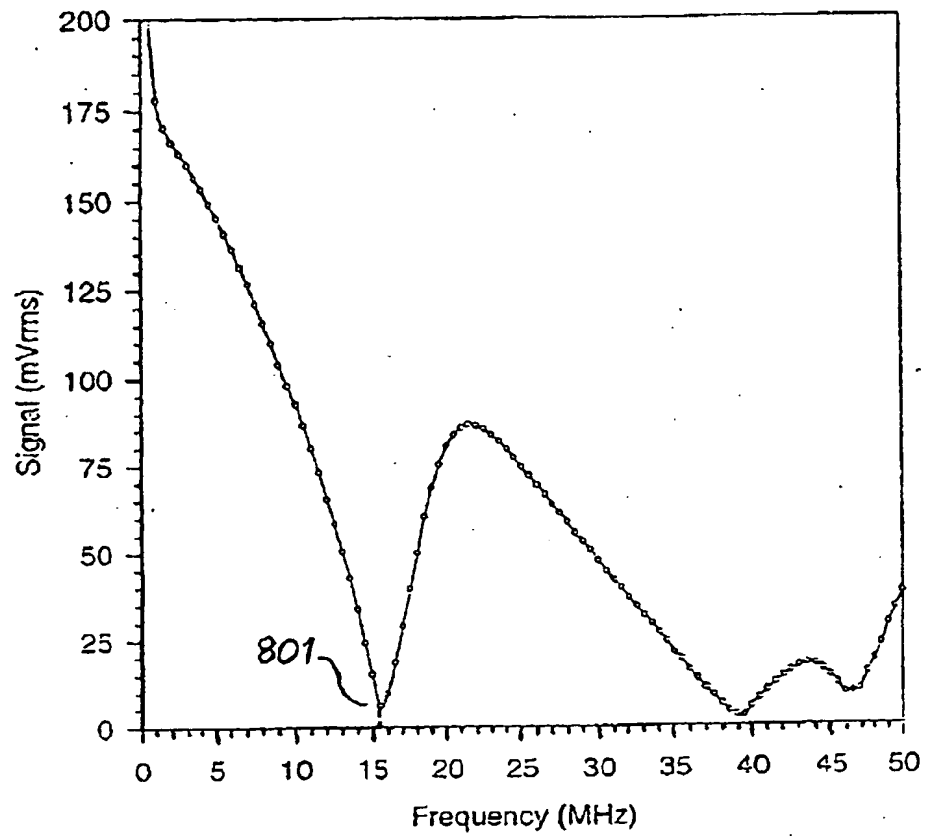
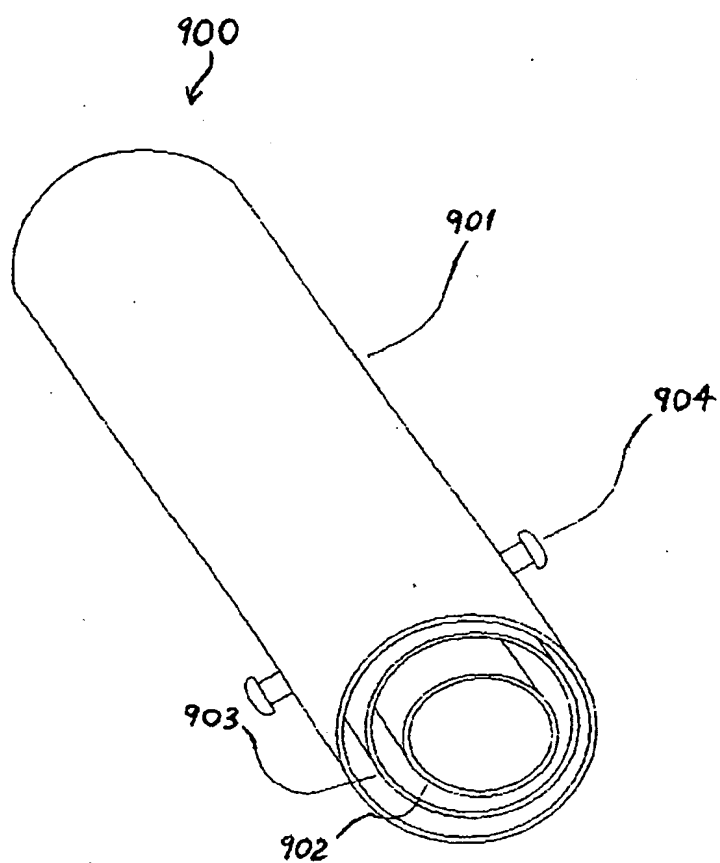


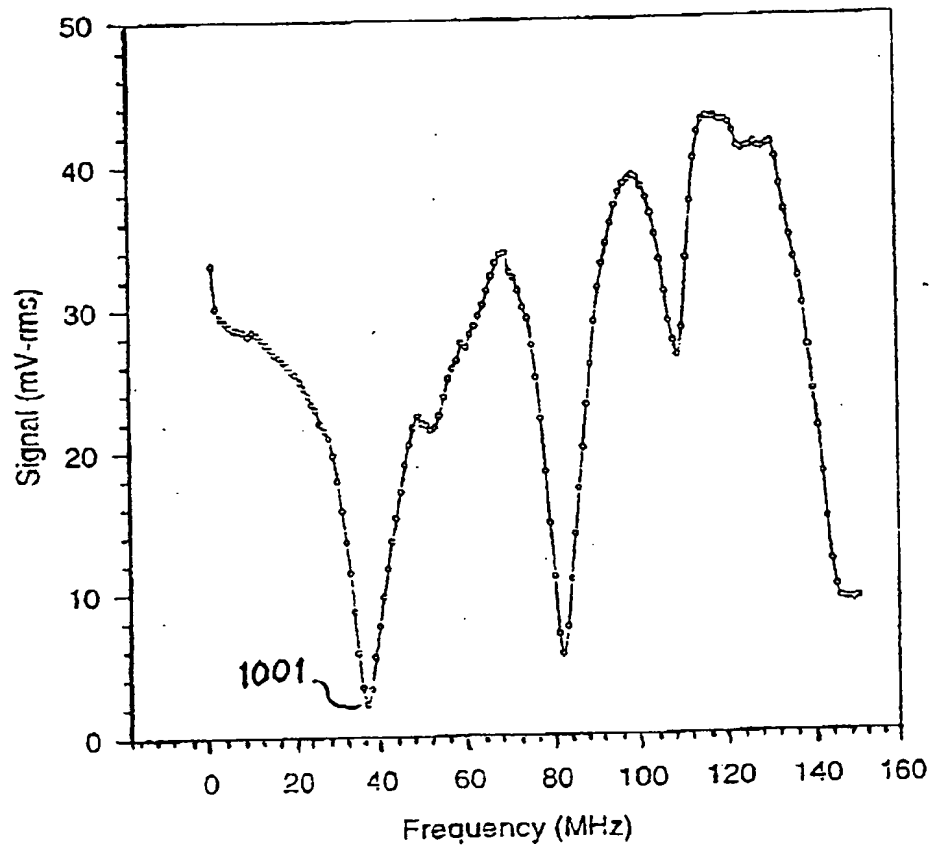
FIG. 5

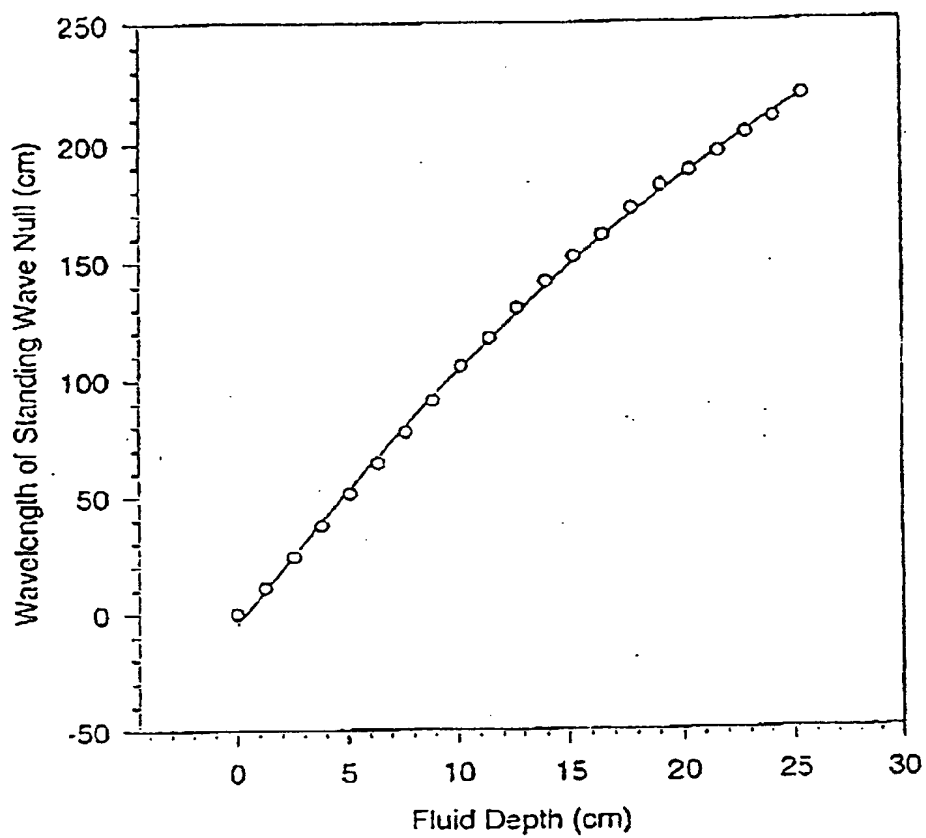
**FIG. 6**

**FIG. 7**

**FIG. 8**

**FIG. 9**

**FIG. 10**

**FIG. 11**

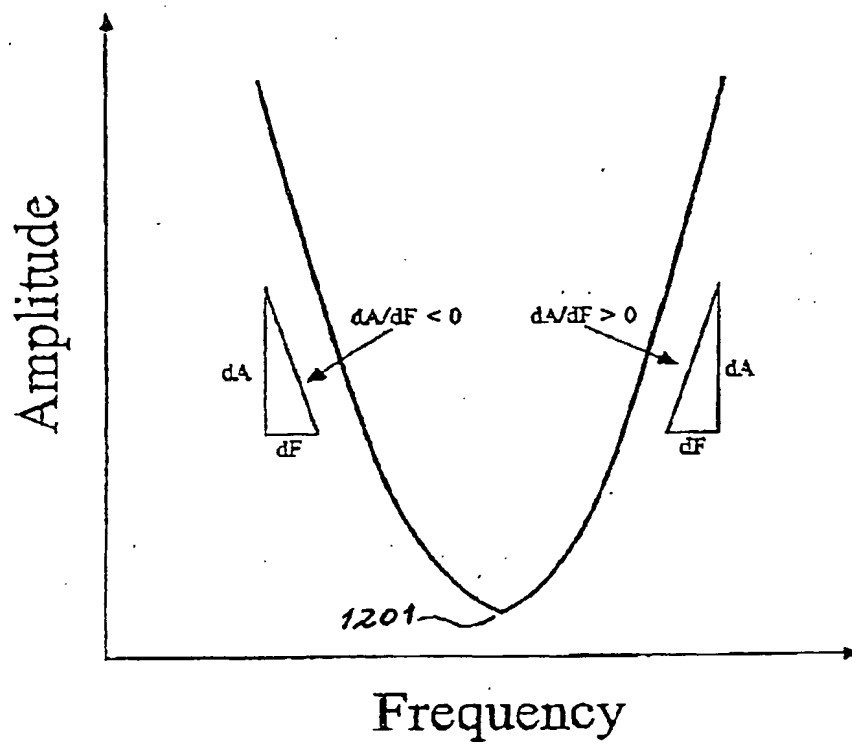


FIG. 12

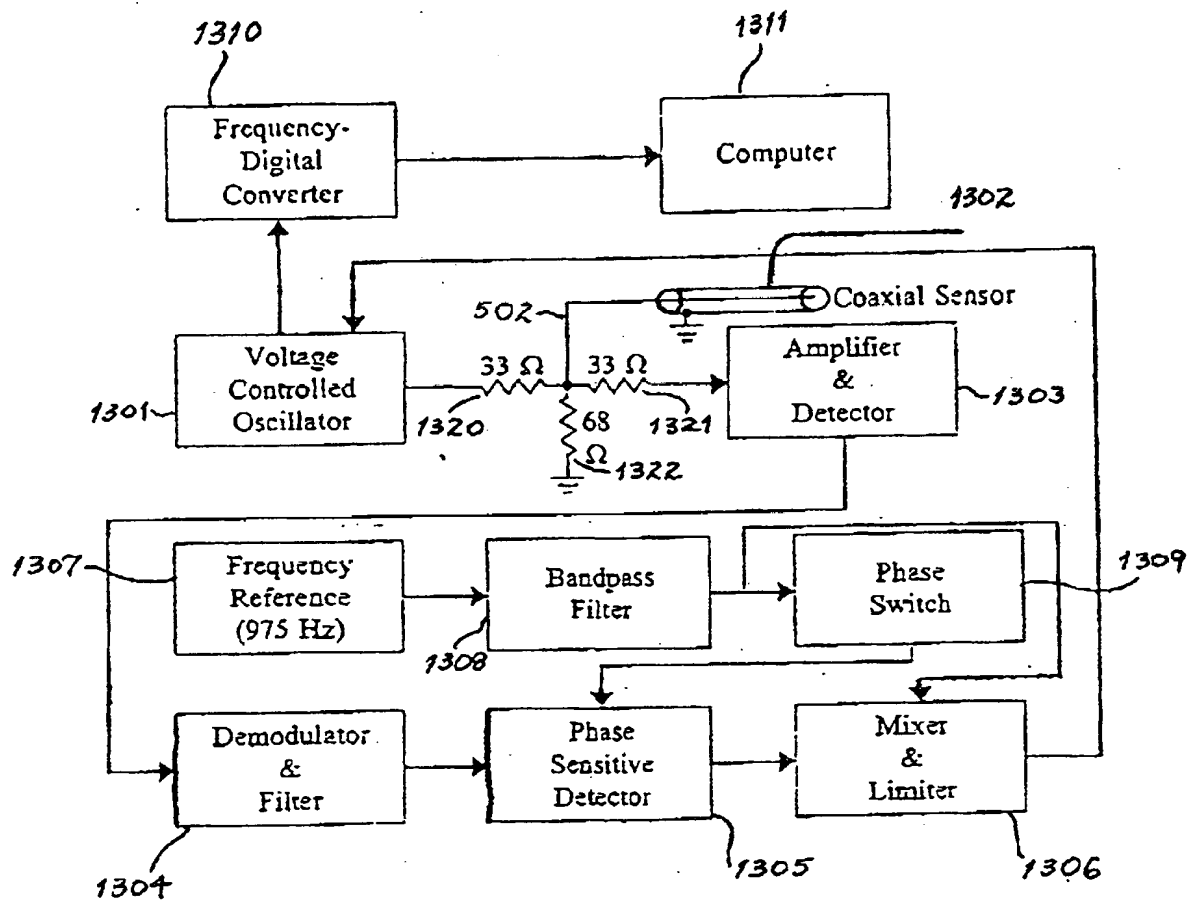
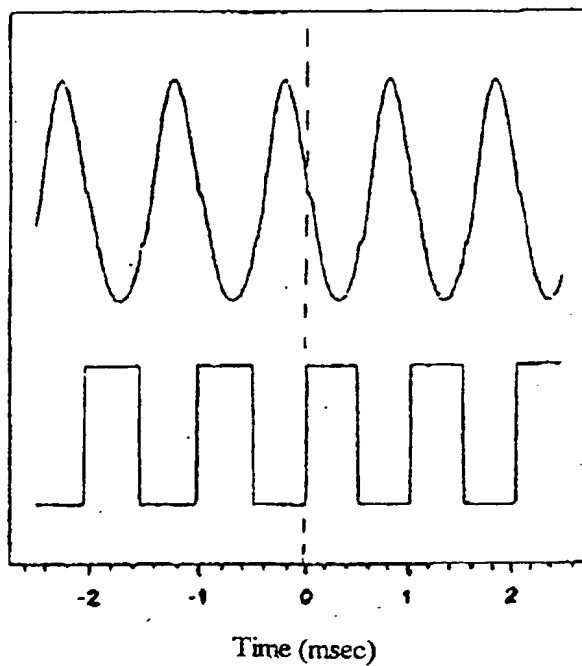
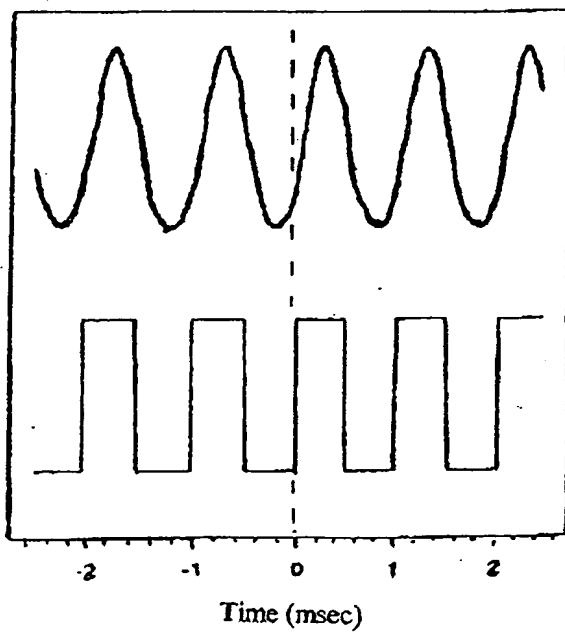
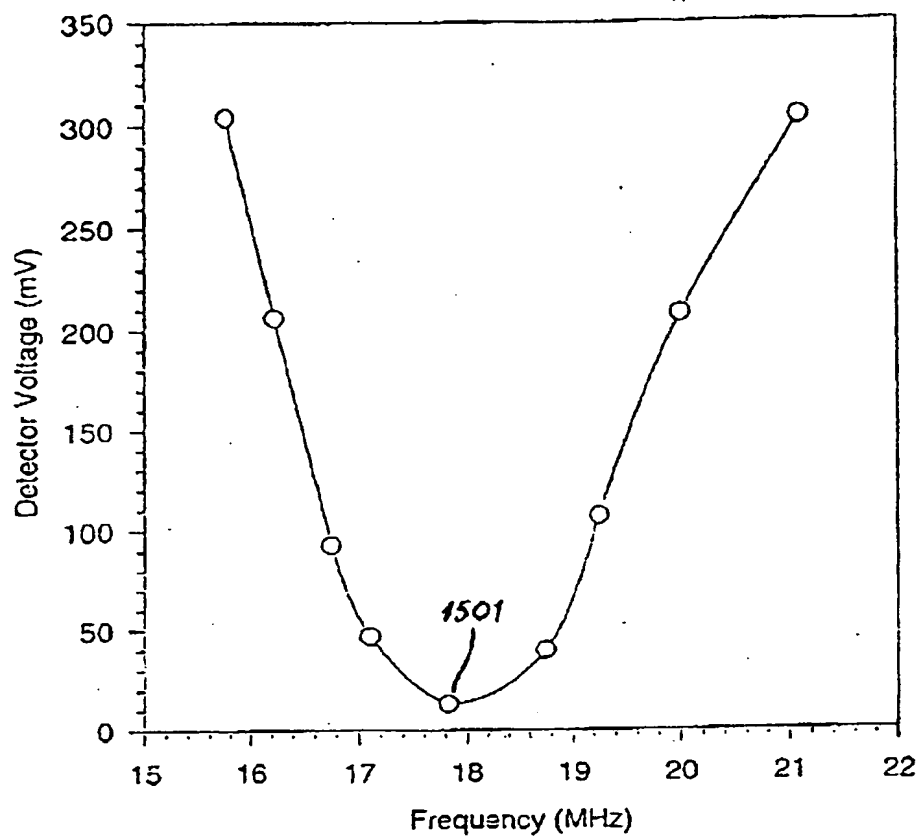
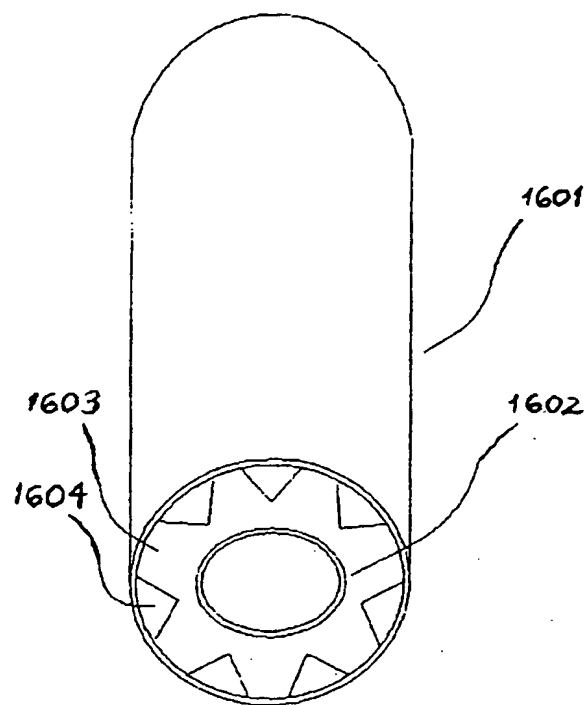


FIG. 13

**FIG.14A****FIG. 14B**

**FIG. 15**

**FIG. 16**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/07277

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G01F 23/00

US CL : 73/290B, 290V

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/290B, 290V, 290R, 149

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST

search terms: transmission, wave, signal, sum, add, liquid, volume, fluid, material

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--|-----------------------|
| X | US 4,589,281 A (ALDRICH) 20 May 1986 (20.05.1986), abstract and col. 1, line 1 thru col. 2, line 68. | 1-3, 6-10 |
| X | US 5,249,463 A (WILLSON et al.) 05 October 1993 (05.10.1993), abstract, figure 1. | 4, 5 |
| A | US 3,944,994 A (FANSHAWE) 16 March 1976 (16.03.1976), abstract. | 1-10 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

| | |
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Date of the actual completion of the international search

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Date of mailing of the international search report

27 JUL 2001

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-9230

Authorized officer

KATINA WILSON

Telephone No. (703) 305-4900

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